銀河形成シミュレーションで探るrプロセス元素に富んだ星の起源

平居悠 (HIRAI, Yutaka)

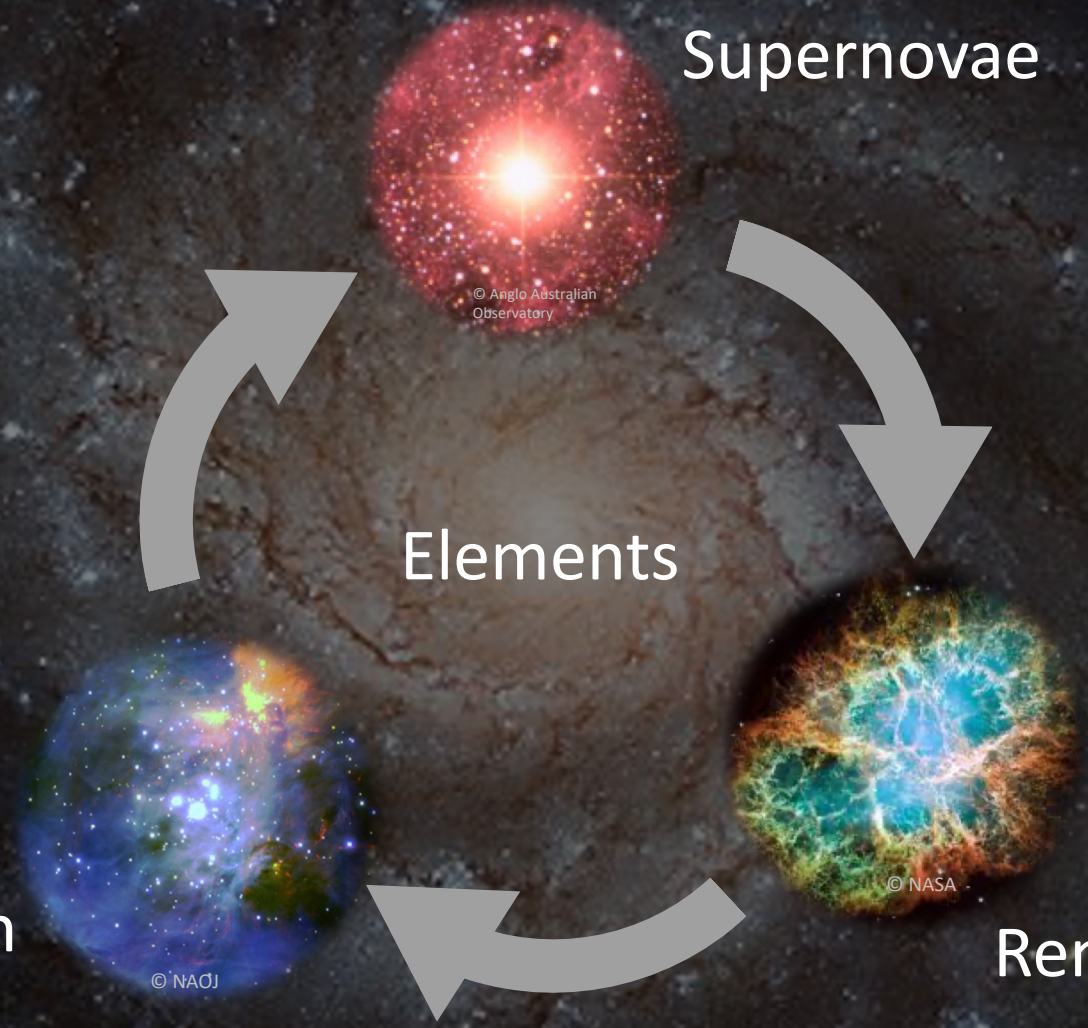
ノートルダム大学物理天文学科/東北大学天文学教室

日本学術振興会特別研究員-CPD (国際競争力強化研究員)

Yutaka Hirai, Timothy C. Beers, Masashi Chiba, Wako Aoki, Derek Shank, Takayuki R. Saitoh, Takashi Okamoto, Junichiro Makino, MNRAS, 517, 4856–4874 (2022)

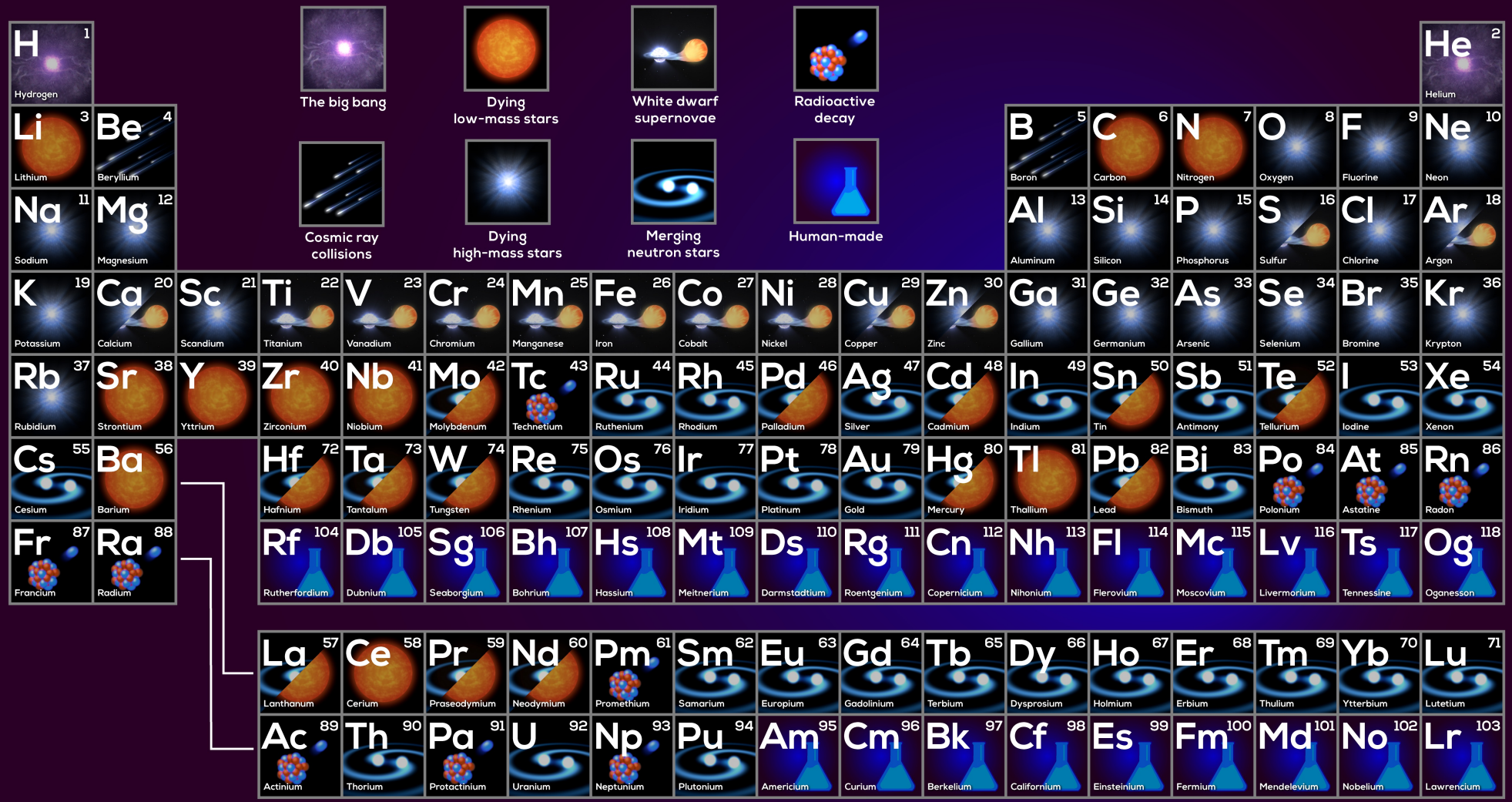
How was the Milky Way formed?

Galactic Chemical Evolution



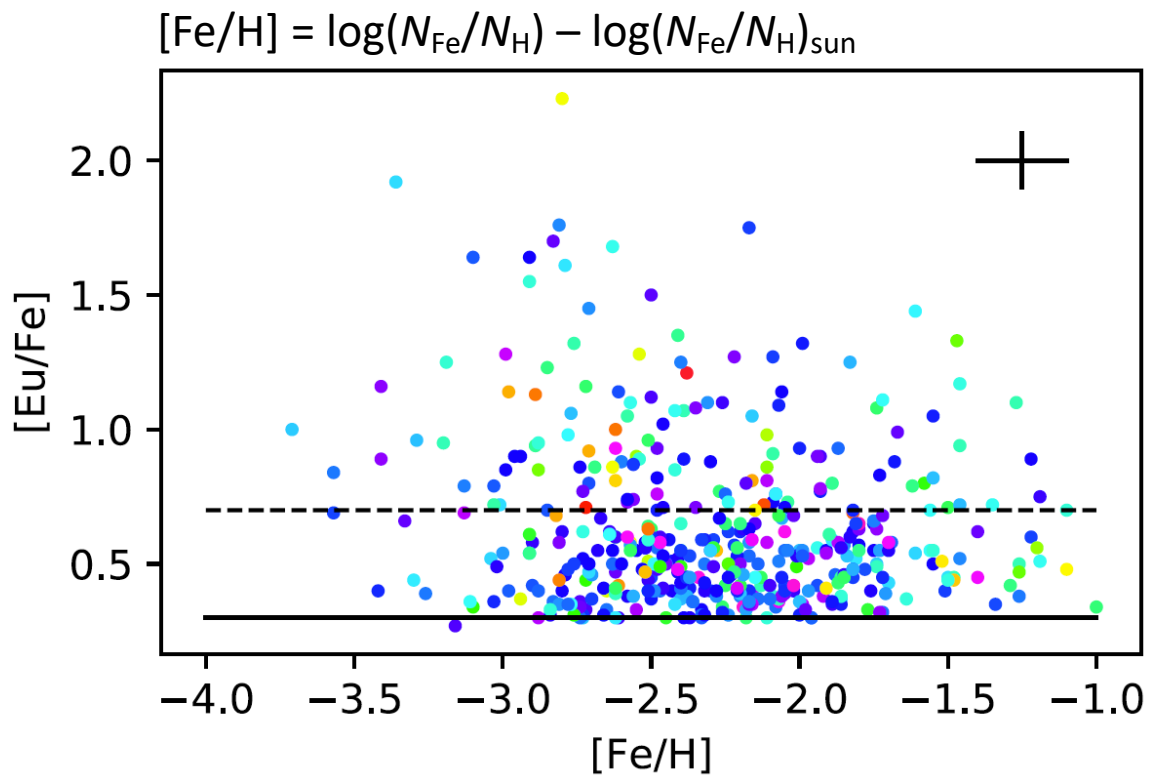
Yutaka Hirai – yhirai2@nd.edu

Origins of the Elements

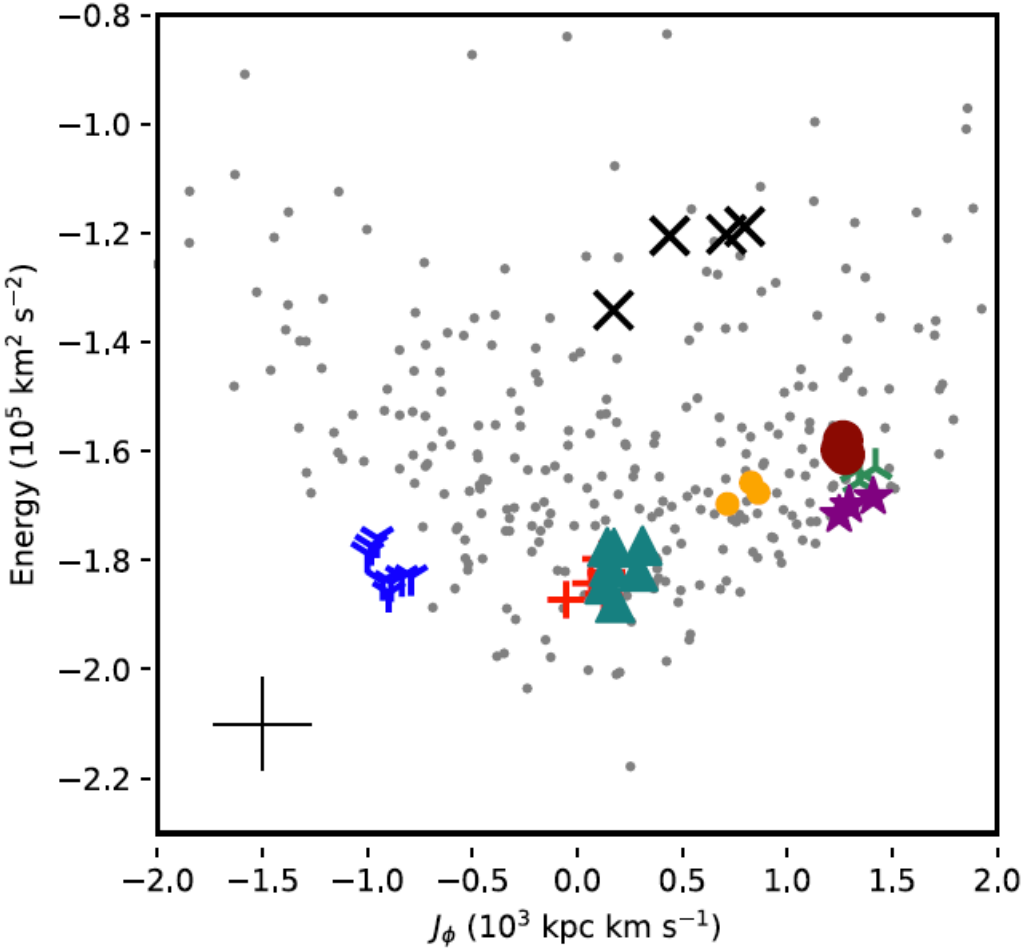


This periodic table depicts the primary source on Earth for each element. In cases where two sources contribute fairly equally, both appear.

Chemo-dynamically tagged groups –Possible dwarf galaxy origin of r-process enhanced stars



Gudin+21
(see also, Roederer+18, Shank+23, Hattori+23)



How can we extract the galaxy formation history from chemical abundances?

Code

ASURA — Saitoh et al. (2008; 2009)

N-body/smoothed particle hydrodynamics — Saitoh & Makino (2013)

Cooling/heating — Cloudy: Ferland et al. (2013)

Star formation — Okamoto et al. (2003)

Supernova feedback — Hopkins et al. (2018)

Metal diffusion — Shen et al. (2010); YH & Saitoh (2017)

Star particles' →

Mass
Metallicity

← Lifetime

Yields

Chemical Evolution Library (CELib) — Saitoh (2017); Hirai et al. (2021)

Core collapse supernovae — Nomoto et al. (2013)

Type Ia supernovae — Seitenzahl et al. (2013)

Neutron star mergers — Wanajo et al. (2014)

AGB stars — Karakas (2010)

Cosmological zoom-in simulation of a Milky Way-like galaxy

YH+TS, JM (2022)
MNRAS, 517, 4856

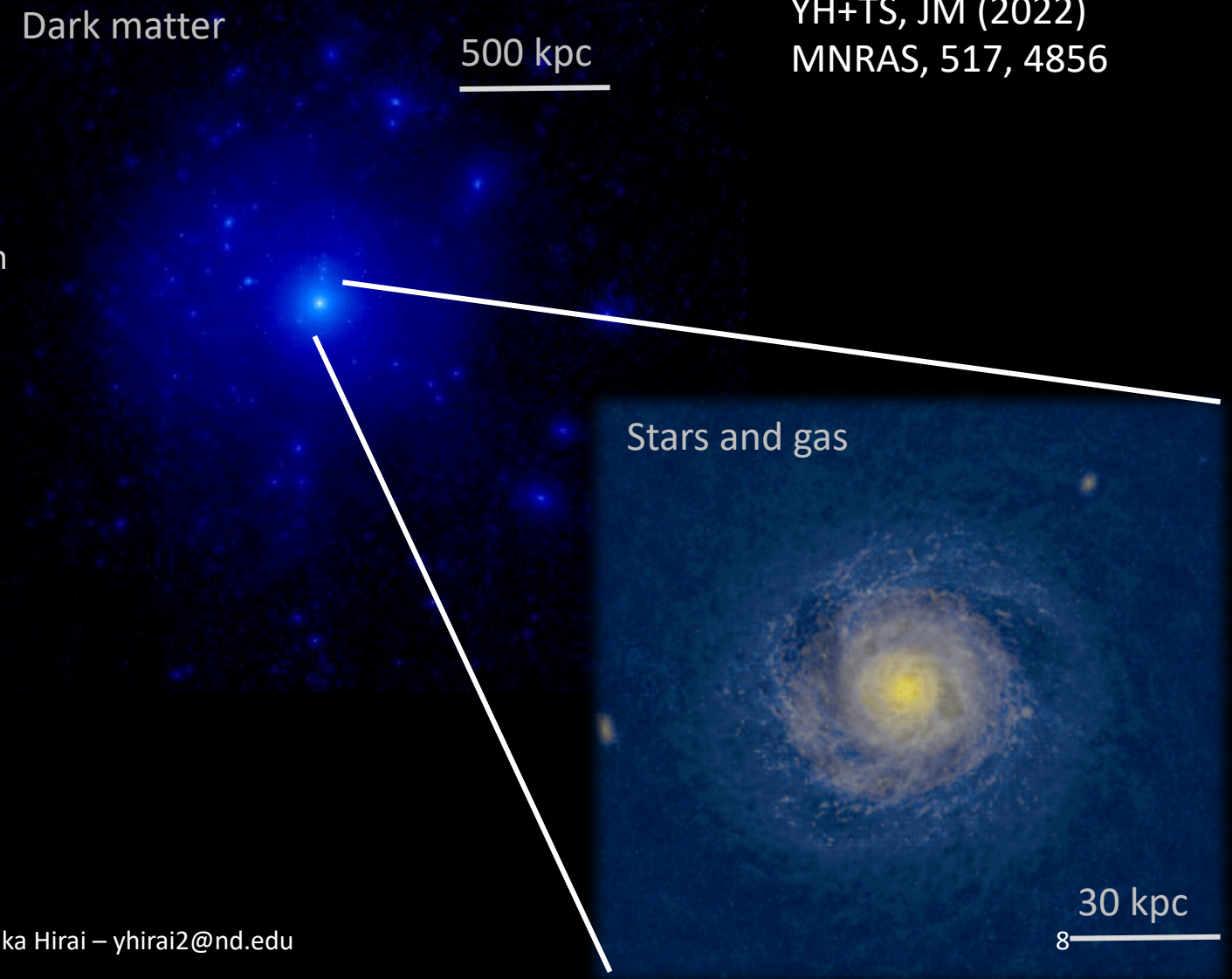
Box size: $(36\ h^{-1}\ \mathrm{Mpc})^3$

Total mass of the halo: $1.2 \times 10^{12}\ M_{\mathrm{sun}}$

Cosmological parameters:
Planck Collaboration (2016)

The Initial mass of one gas particle:
$1.3 \times 10^{4}\ M_{\mathrm{sun}}$

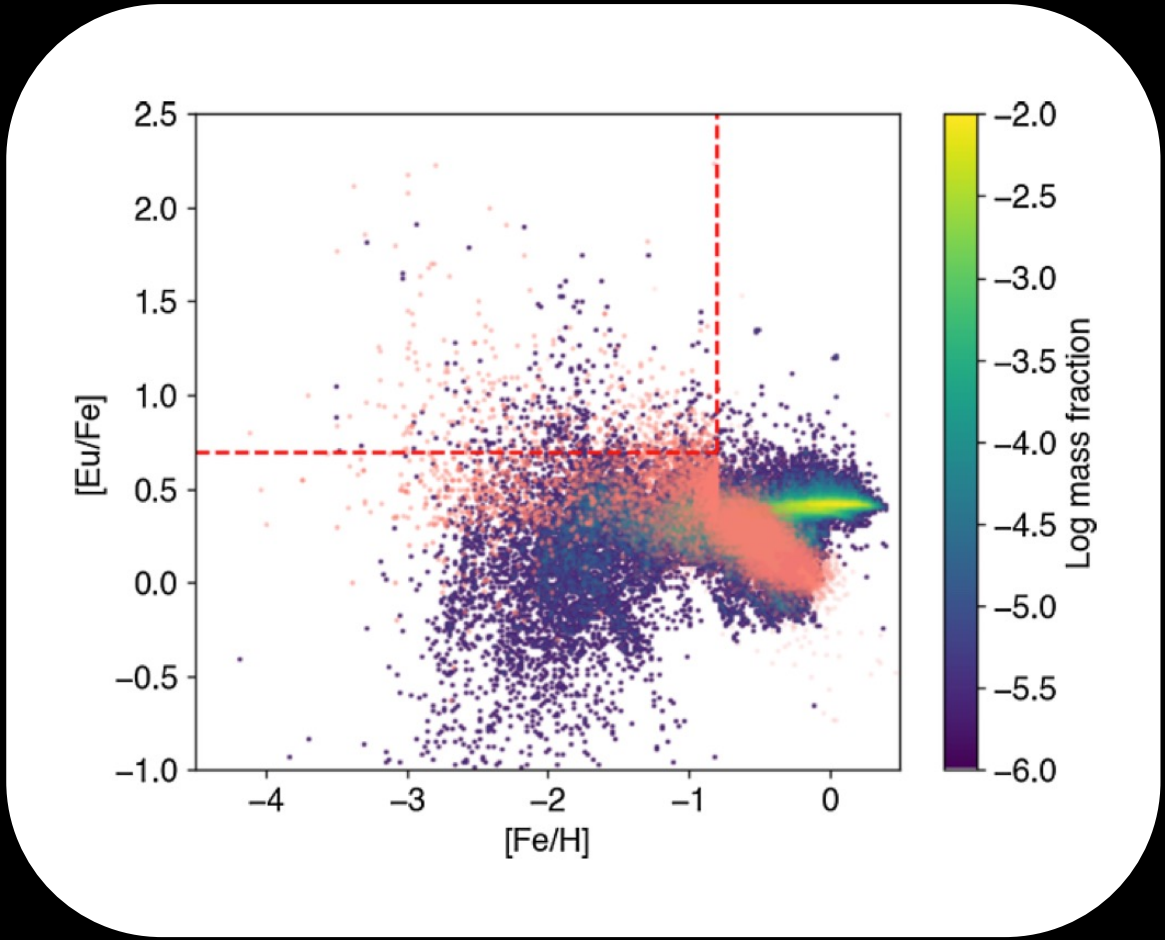
Gravitational softening length:
80 pc



Yutaka Hirai – yhirai2@nd.edu

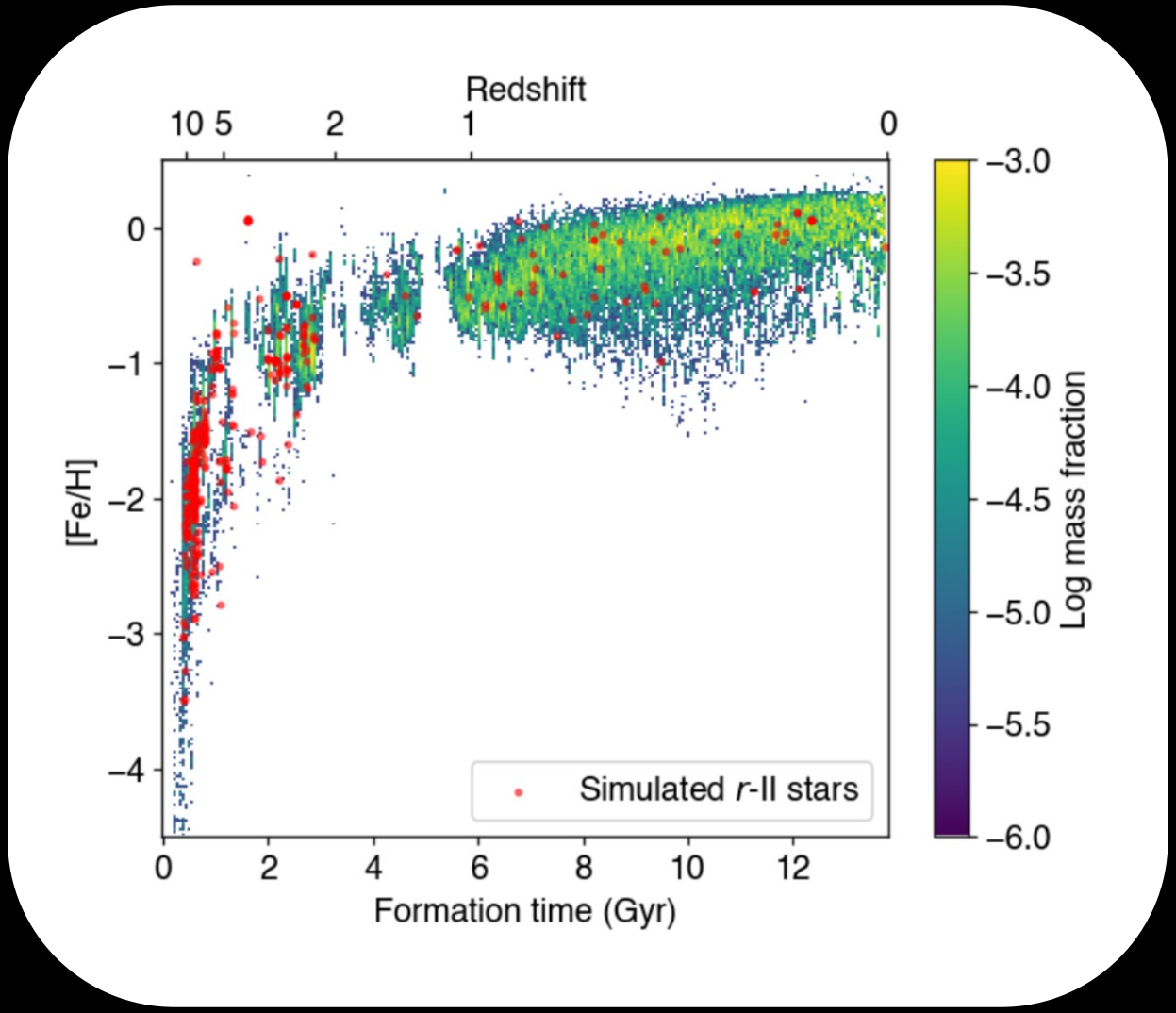
Simulated [Eu/Fe] vs. [Fe/H]

YH+22



Star-to-star variations for [Eu/Fe] in [Fe/H] < –2

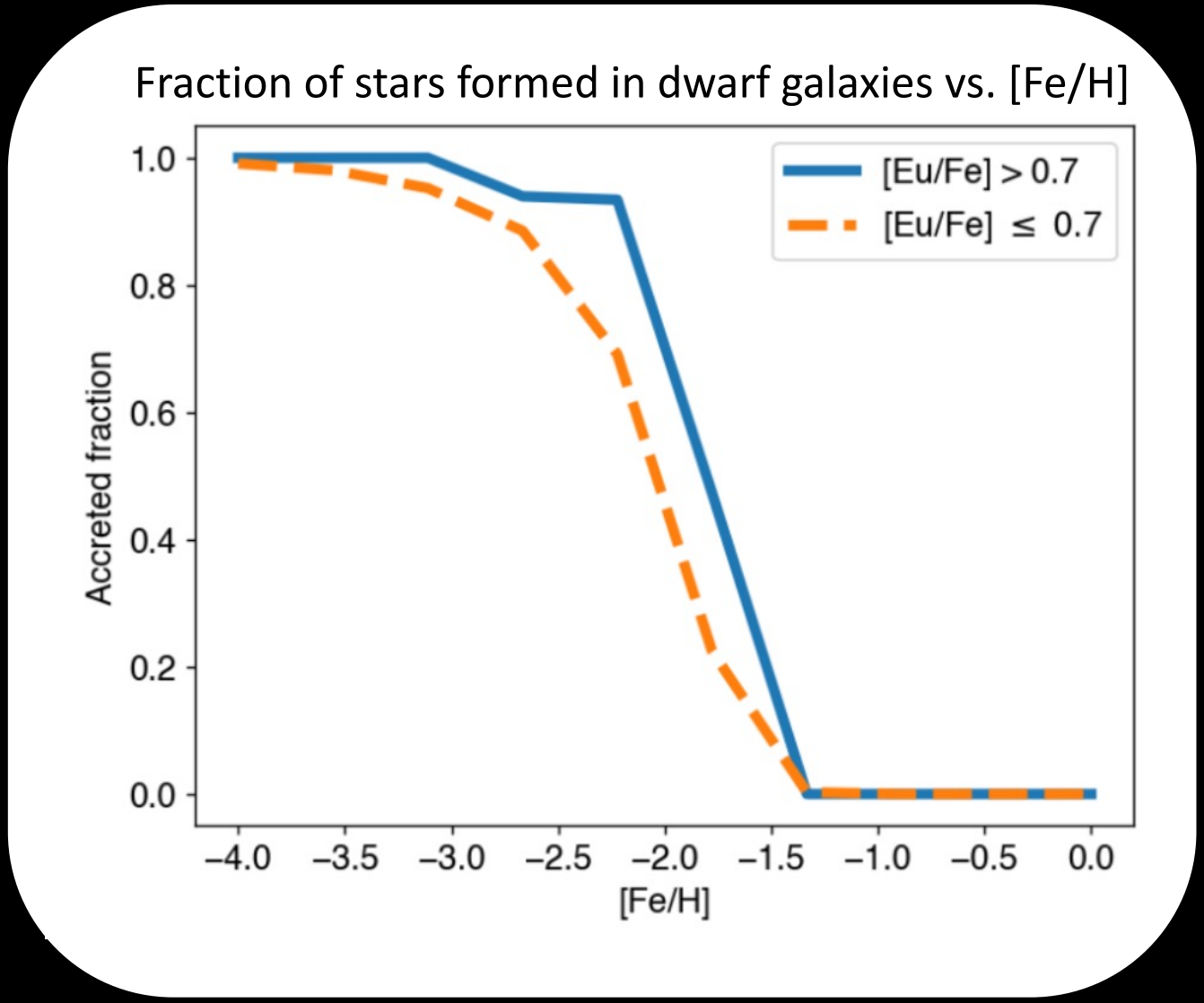
When were *r*-process enhanced (RPE) stars formed?



Over **90%** of RPE ([Eu/Fe] > 0.7) stars are formed within **4 Gyr.**

YH+22

Where were RPE stars formed?

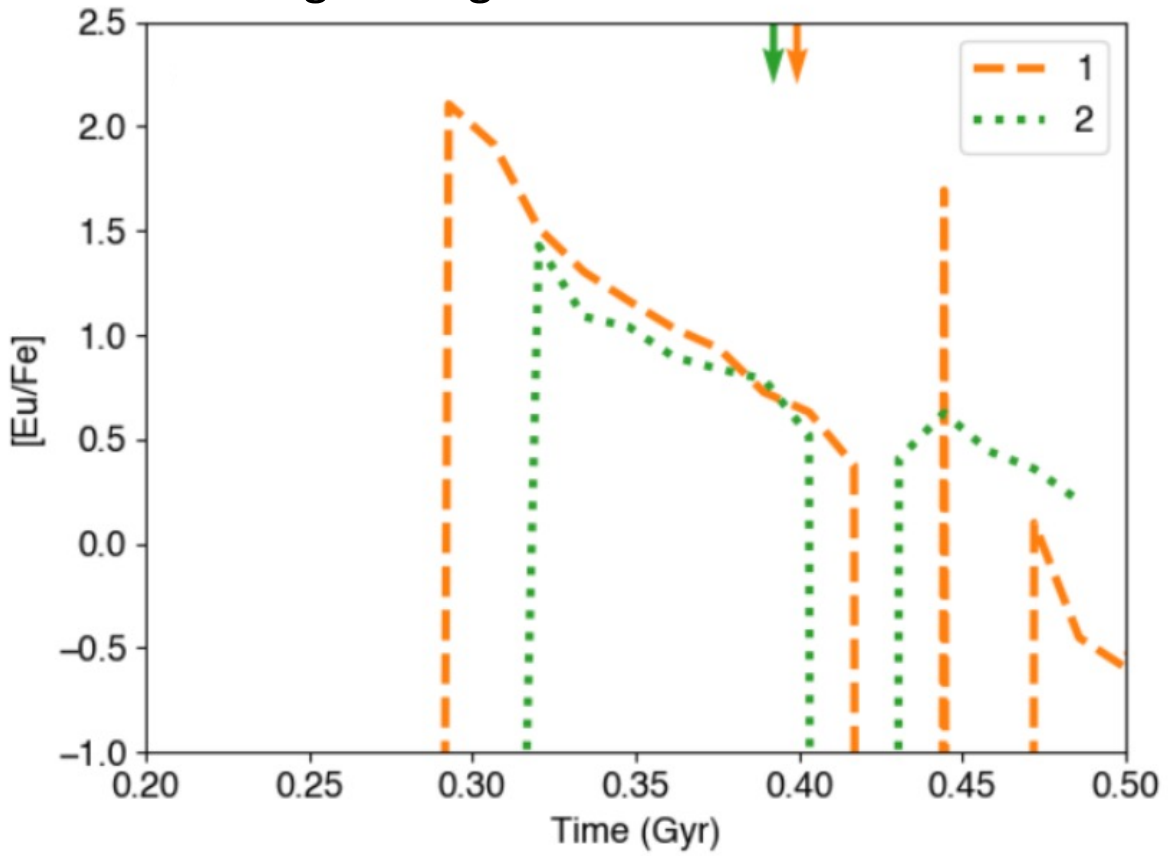


Over **90%** of RPE stars with [Fe/H] < −2 are formed in **dwarf galaxies** accreted to the Milky Way.

YH+22

How were RPE stars formed?

Mean gas phase [Eu/Fe] in low-mass building block galaxies vs. time



RPE stars with [Fe/H] < −2.5 are formed in low-mass dwarf galaxies **largely enhanced in r-process elements**.

YH+22

How can we extract the galaxy formation history from chemical abundances?

R-process enhanced stars with [Fe/H] < −2.5 could be a relic of accreted dwarf galaxies.

What's next?

How were star clusters formed in the context of galaxy formation?

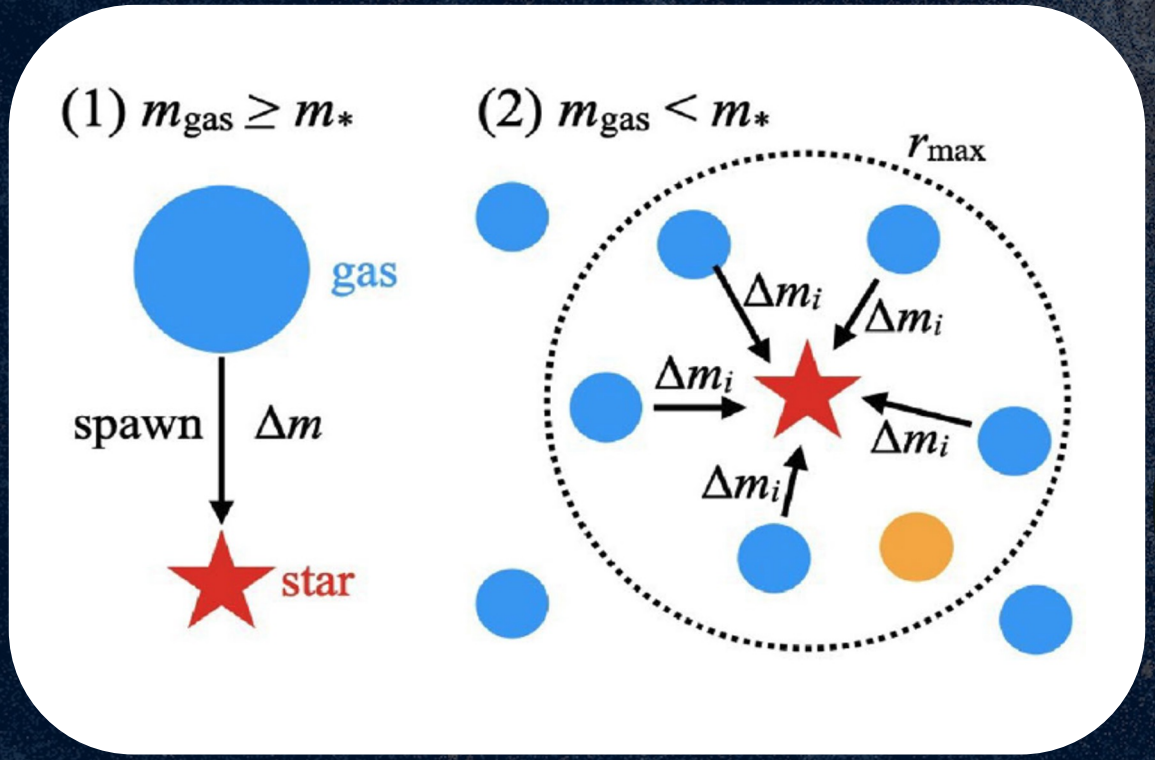
How can we extract the accretion histories of dwarf galaxies over 10 Gyr?

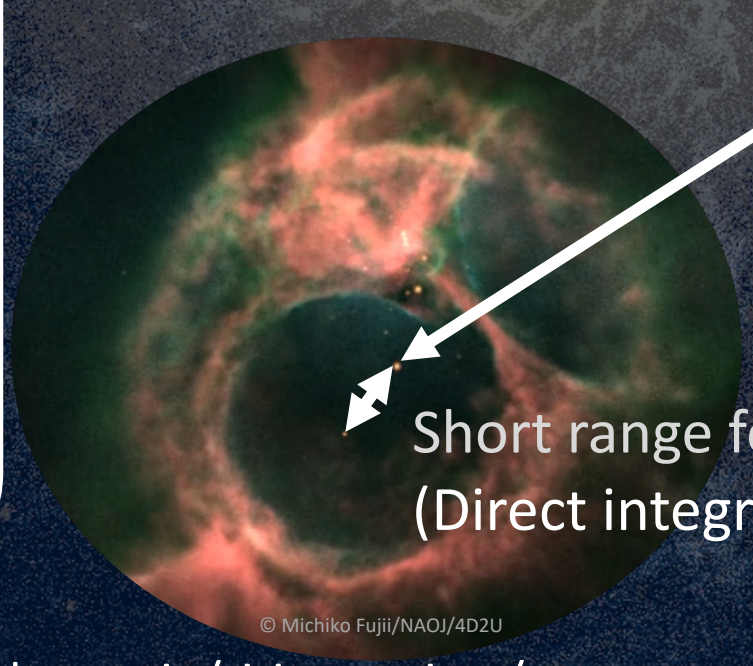
Simulations Resolving Individual Stars (SIRIUS) project

Star-by-star simulations for dwarf galaxies and star clusters

YH, Fujii, Saitoh 21
Fujii, Saitoh, Wang, YH+21
Fujii, Saitoh, YH, Wang+21

Star formation model





Long range forces
(Tree)

Short range forces
(Direct integration)

Project website: https://sites.google.com/g.ecc.u-tokyo.ac.jp/sirius-project/

Conclusions

- We perform a high-resolution cosmological zoom-in simulation of a Milky Way-like galaxy.
- Over **90%** of r-II stars ([Eu/Fe] > 0.7) are formed **within 4 Gyr** from the Big Bang in **dwarf galaxies** accreted to the Milky Way at a later time.
- RPE stars with [Fe/H] < −2.5 are formed in **low-mass dwarf galaxies** enhanced in *r*-process elements.